RISK-BASED DECISION-MAKING GUIDELINES

Volume 2
Introduction to Risk-based Decision Making

Overview of Assessment Tools

Chapter 5 — Decision Analysis Tools

Chapter Contents

This chapter provides an overview of different decision analysis tools and includes basic instructions for using each tool. The following are the major topics in this chapter:

Summary of Decision Analysis Tools

- **Help structure the decision process**
- **Vary from informal to formal methods**
- **Provide documentation of the decision-making process**

1.0 Summary of Decision Analysis Tools

Decision analysis tools provide a structured process for making decisions. This chapter presents four types of decision analysis tools appropriate for many uses:

- Voting methods
- Weighted scoring methods
- Decision trees
- Optimization methods

The following paragraphs describe three basic features of decision analysis tools:

Help structure the decision process. Decision analysis tools have a basic structure to help you examine options and make a decision.

Vary from informal to formal methods. Some tools have very rigid structures, while others are more flexible. Typically, more highly structured tools provide more complete evaluation but often require much more effort than less structured tools. Although less structured tools usually require fewer skills, they need more input from subject matter experts to make up for issues that the decision-making process might overlook. This wide range of methods allows you to choose the proper level of effort for the complexity of the decision.

Provide documentation of the decision-making process. Decision analysis tools provide written data supporting the results of the decision-making process. This documentation can also be used to make other decisions for similar situations.

Guidelines for Selecting Decision Analysis Tools

- **Level of effort**
- **Uncertainty**
- **Qualitative or quantitative information**

2.0 Choosing Decision Analysis Tools

A few guidelines should be considered when choosing a decision analysis tool. These include the following:

Level of effort

The amount of time and money spent on decision analysis should depend on the expected results of the decision. Some tools are simple and quick, while others require a lot of effort. For example, a $10,000 decision probably does not warrant a $6,000 decision analysis.

Uncertainty

All data used in the decision-making process will have some level of uncertainty, or doubt. Medium to high levels of uncertainty in the data can produce an uncomfortable level of uncertainty in the analysis results. Some decision analysis tools specifically model uncertainty in the input data.

Qualitative or quantitative information

Most decision analysis tools accept numeric inputs. These inputs range from equipment performance specifications to numerical rankings of features or competing alternatives. Some tools handle qualitative inputs (e.g., good reliability, easy to operate, more expensive) more easily than others; however, some tools cannot handle qualitative inputs at all. Most tools provide numeric outputs, such as scoring or ranking of alternatives, for making decisions. The level of detail in the results depends on the complexity of the tool.

Voting Methods

Results for the Plurality and Ranking Voting Methods									
	Participant					Plurality		Ranking	
Option	A	B	C	D	E	No. of #1 Votes	Position	Average Rank	Position
1	1	1	4	4	5	2	2	3	1
2	8	6	1	1	1	3	1	3.4	3
3	2	4	7	8	3	0		4.8	4
4	7	5	2	7	4	0		5	5
5	3	7	3	5	7	0		5	5
6	6	3	6	6	6	0		5.4	7
7	4	2	5	3	2	0		3.2	2
8	5	8	8	2	8	0		6.2	8

3.0 Summary of Voting Methods

Voting methods for decision analysis use a team of experts to review and vote on different choices. These methods rely on the ability of the stakeholders to understand the advantages and disadvantages of each choice and to vote accordingly.

Brief summary of characteristics

- Minimal effort is required. Modeling of problems requires little information, and the models usually have little structure, with decision factors not plainly identified
- Uncertainty is not specifically modeled but is addressed informally
- Outputs are quantitative

Situations for using voting methods

- Large number of stakeholders
- Possible negative results from the decision are minimal
- Uncertainty and sensitivity analyses are not needed
- Documentation is not required

Advantages of voting methods

- Quick to perform
- Easy to use
- Can be used for almost any decision

Example

The following is a simple example demonstrating the plurality and ranking voting methods. The table below shows the plurality and ranking method used to decide on options 1-4. Each person (A-E) ranked the options in order of preference.

Plurality steps

Results for the Plurality Voting Method							
	Participant					Plurality	
Option	A	B	C	D	E	No. of #1 Votes	Position
Oil spill control system 1	1	1	2	2	2	2	2
Oil spill control system 2	4	3	1	1	1	3	1
Oil spill control system 3	2	4	3	3	3	0	
Oil spill control system 4	3	2	4	4	4	0	

Step 1. Each person ranks the alternatives. The table shows that Options 1 and 2 received all of the first phase votes.

Step 2. Select the alternative with the most #1 votes. Option 2 is selected using the plurality method.

Ranking steps

Results for the Ranking Voting Method							
	Participant					Ranking	
Option	A	B	C	D	E	Average Rank	Position
Oil spill control system 1	1	1	2	2	2	1.6	1
Oil spill control system 2	4	3	1	1	1	2.0	2
Oil spill control system 3	2	4	3	3	3	3.0	3
Oil spill control system 4	3	2	4	4	4	3.4	4

Step 1. Each participant ranks all alternatives. The rows of numbers under participants A - E show the ranking of each option by each participant.

Step 2. The rankings are summed and averaged. The average rank column shows the average ranking of each option.

Step 3. The alternative with the lowest average is selected. Option 1 is chosen using the ranking method as shown by the position column.

Disadvantages of voting methods

- When voting methods are used, there is usually very little written data to show how a decision was reached. This can lead to second-guessing of the decision, especially by individuals outside the voting group. Lack of documentation limits the ability to use the information in making other, similar decisions.
- Voting methods often do not make use of all information available to the decision-making group. For example, the plurality method does not consider the ranking of options, and neither the ranking method nor the plurality method considers the way an individual prefers one option over another.
- Strengths and weaknesses of options are unclear. The negative aspects of an alternative are usually not described, and the reasons for supporting an option are not documented.
- Typically, the issues or options are only listed and not described. This can lead to confusion as to what is really being voted on.
- The information from each expert is typically weighted equally, regardless of the actual experience of each expert.

Weighted Scoring Methods

		Value (Score)				Weighted Scores			
Factor	Weight	Pump A	Pump B	Pump C	Pump D	Pump A	Pump B	Pump C	Pump D
Safety	30%	Very High (100)	High (75)	Medium (50)	Medium (50)	30	22.5	15	15
Flowrate	20%	2.6 (73)	2.5 (72.5)	1.3 (45.5)	2.1 (70.5)	14.6	14.5	9.1	14.1
Cost	50%	$520 (48)	$270 (73)	$560 (44)	$400 (60)	24	36.5	22	30
Initial		$500	$230	$430	$350				
Operating		$20	$40	$130	$50				
					Total	68.6	**73.5**	46.1	59.1

4.0 Summary of Weighted Scoring Methods

Weighted scoring methods plainly identify decision factors, and each alternative is compared to the factors. The decision models address many factors. A numerical value is assigned to each alternative for each factor. Various factors are weighted differently. The weighted numerical values are added, and the alternative with the highest score is the best overall alternative.

Brief summary of characteristics

- Both qualitative and quantitative inputs are easily handled
- Each alternative is given an overall score

Situations for using weighted scoring methods

- Group or individual decision making
- Few alternatives (<10)
- Timing is not an issue

Example

The example on the following pages demonstrates the steps for using a weighted scoring method to make decisions. The decision involves choosing a fuel pump for an onboard system.

Weighted scoring steps

Step 1. Define the decision factors of interest. For choosing a fuel pump, the following factors could be considered:

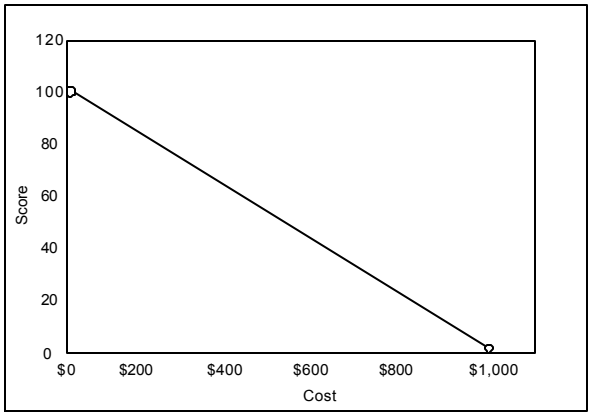
- Safety
- Flowrate (i.e., capacity)
- Cost
  - initial
  - operating

Step 2. Assign importance levels, or weights, to each decision factor. Weight each decision factor based on its importance in the decision-making process. Subject matter experts need to participate in this step.

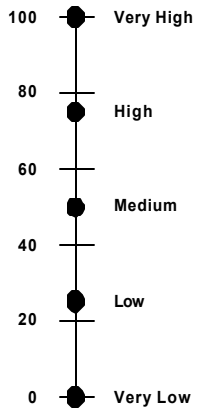
Factor	Weight
Safety	30%
Flowrate	20%
Cost	50%
	100%

Step 3. Develop scales for changing decision factor values into scores. A scale of some type allows the decision maker to rate the factors of each option. Scales can be created in a variety of forms. The following are scales for cost, safety, and flowrate.

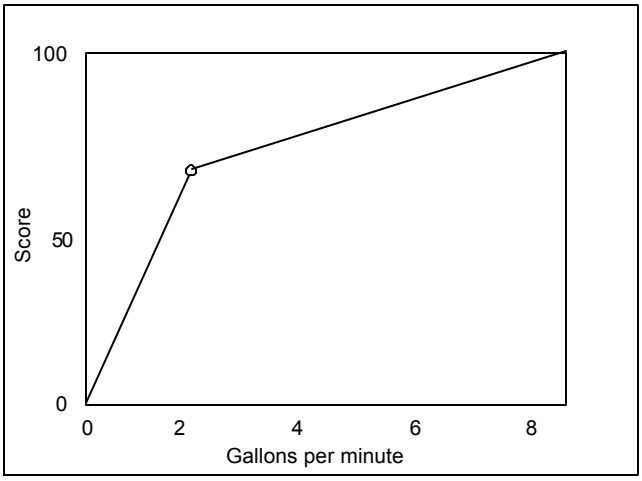
Evaluation scale for cost



Evaluation scale for safety



Evaluation scale for flowrate



Step 4. Score each decision factor for each alternative, multiply the score by its weight, and sum the weighted scores. The table below shows the ratings of four pumps. For example, Pump D has a medium safety (which translates to a 50), a flowrate of 2.1 gallons per minute (which translates to 70.5), and a cost of $400 (which translates to 60). The weighted scores are the weights of each factor multiplied by the score.

		Value (Score)				Weighted Scores			
Factor	Weight	Pump A	Pump B	Pump C	Pump D	Pump A	Pump B	Pump C	Pump D
Safety	30%	Very High (100)	High (75)	Medium (50)	Medium (50)	30	22.5	15	15
Flowrate	20%	2.6 (73)	2.5 (72.5)	1.3 (45.5)	2.1 (70.5)	14.6	14.5	9.1	14.1
Cost	50%	$520 (48)	$270 (73)	$560 (44)	$400 (60)	24	36.5	22	30
Initial		$500	$230	$430	$350				
Operating		$20	$40	$130	$50				
					Total	68.6	**73.5**	46.1	59.1

The results show that Pump B has the highest total weighted score and, therefore, would be the best choice.

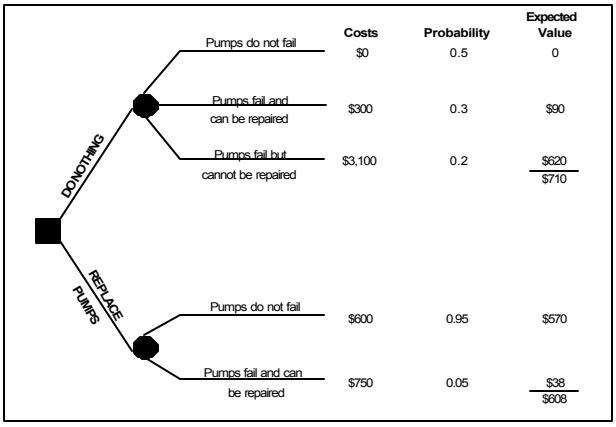
Advantages of weighted scoring methods

- Address different factors, such as the pump flow rate and the cost of the pump
- Different types of scales can be used for the various factors
- Decision factors are plainly identified and weighted so the group can reach an agreement on each item
- Can be used by individuals or groups

Disadvantages of weighted scoring methods

- Time consuming — decision factors and evaluation scales must be developed, and each alternative must be compared against each evaluation scale
- Basic scoring models do not plainly account for uncertainty
- Difficult to address future events or pending decisions
- Decision factors may be linked, which may result in double counting. For example, the age of the vessel is linked both to the number of associated accidents and the vessel's repair costs

Decision Trees



5.0 Summary of Decision Trees

The decision tree method of decision analysis uses a tree structure to illustrate the decision process. Probabilities are assigned to events, and the expected value of each alternative is determined. The alternative with the most attractive total expected value is chosen. Depending on the decision, the most attractive expected value may be the highest or lowest number.

Brief summary of characteristics

- Decision trees require (1) sequential modeling of decision points and chance events and (2) the development of probabilities and outcome values for each branch
- Uncertainty of inputs is plainly modeled in the tree branches
- Sensitivity analysis can be implemented easily but is best approached with commercial software
- Inputs and outputs are quantitative. Qualitative inputs are difficult to address.

Situations for using decision trees

- Sequential decision models
- Uncertain inputs

Example

The following example shows the steps for performing a decision tree analysis. The problem is to determine whether aging pumps should be replaced. Below are information about the pumps, the available options, and costs associated with the options.

Pumps are aging

- If pumps fail, they are difficult to repair, and some spare parts are no longer available
- Two major options
  - do nothing
  - replace pumps

Possible outcomes if "do nothing" option is selected

- Pumps do not fail (50%)
- Pumps fail and can be repaired (30%)
- Pumps fail and cannot be repaired (20%)

Possible outcomes if "replace pumps" option is selected

- New pumps may also fail (5%)
  - failure rate should be lower
  - all failures can be repaired

Costs associated with options

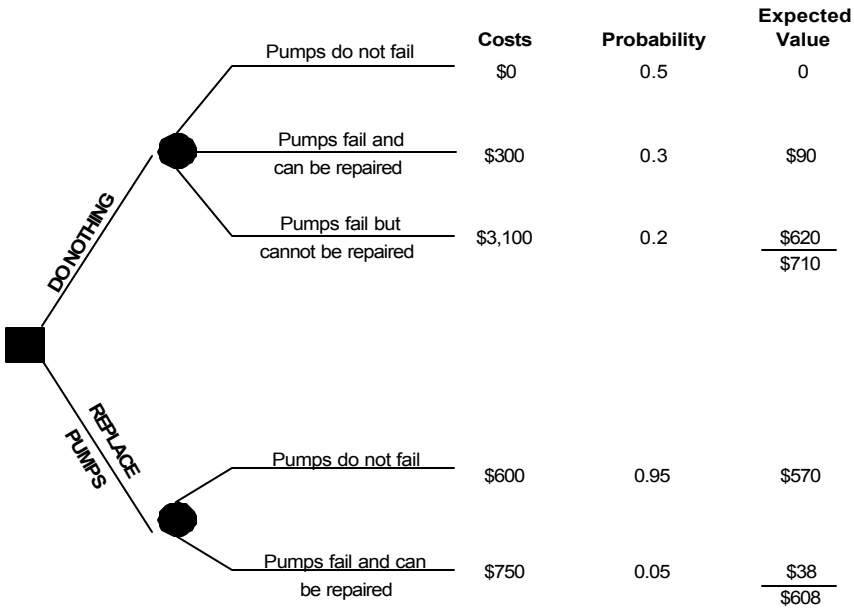
- Replacement pumps cost $500, and related labor costs for installation are $100
- There is no downtime associated with planned replacement of the pumps
- Repairing old pumps costs $200 for labor and $100 in downtime
- If old pumps fail and cannot be repaired, labor costs for installation are $100 and downtime costs are $2,500
- Repairing new pumps costs $100 for labor and $50 in downtime

Decision tree steps

Step 1. Draw a decision tree. The tree below represents the pump problem.

- Use a ■ for a decision
- Use a ● for an occurrence

Step 2. Assign probabilities to the outcomes. Use data and subject matter experts to estimate probabilities of outcomes occurring. For example, in the tree above, the estimated probability the pumps do not fail if nothing is done is 50%.



Step 3. Assign costs or benefits (opposite sign of cost) to the outcomes. If there is a cost and benefit, add them. Consider the following types of cost:

- Cost of procurement
- Cost of labor
- Cost of downtime to install
- Benefits of new pumps and control system

In the example, the cost of replacing the pumps and the pumps not failing is $600.

Step 4. Determine expected values of options. Multiply the cost or benefit by its probability to figure out the expected value at the outcome. Add the expected values of the outcomes for each alternative to arrive at the alternative's expected value.

		Costs						
Option	Outcome	Pumps	Labor	Downtime	Total Cost	Probability	Expected Value	Notes
Do Nothing	Pumps don't fail	$0	$0	$0	$0	50%	$0	
	Pumps fail and can be repaired	$0	$200	$100	$300	30%	$90	
	Pumps fail but can't be repaired	$500	$100	$2,500	$3,100	20%	$620	1
							$710	
Replace Pumps	Pumps don't fail	$500	$100	$0	$600	95%	$570	2
	Pumps fail and can be repaired	$500	$200	$50	$750	5%	$38	3, 4
							$608	

Notes

1 - Large downtime costs are the result of procurement time ($2,500), not installation time

2 - Labor costs are for installation of the pumps ($100)

3 - Labor costs include installation of the pumps ($100) and repairs ($100)

4 - New pumps can be repaired for 50% of the downtime costs of the old pumps

The table above shows the total cost, the probability, and the expected value of each option. For example, the expected value of replacing the pumps is $570 plus $38, for a total of $608.

Step 5. Compare expected values of options benefits. Compare expected values and choose the one that meets the decision goals. In this example, the option "replace the pumps" should be chosen because the expected value (in this case a cost) is lower.

Step 6. Examine assumptions. Review assumptions made in estimating costs and probabilities to make sure the results are correct. The notes in the table above are examples of assumptions.

Advantages of decision trees

- Can be used to show a series of conditional choices
- Can be used to show the impact of time on decisions
- Can plainly model uncertainty
- Can produce quantitative results

Disadvantages of decision trees

- All decision factors must be changed into common units. Qualitative inputs may be difficult to convert (e.g., translating community goodwill to dollars, or effects on organizational reputation to dollars)
- Decision trees are harder to develop in a group setting
- Developing and reaching agreement on event probabilities may be difficult
- Qualitative methods are not easily used
- The number of possible outcomes in the model can be extremely large

Other Decision Analysis Tools

- **Optimization Methods**
- **Kepner-Tregoe Decision Analysis**
- **Benefit-cost Analysis**
- **Multiattribute Utility Analysis**

6.0 Other Decision Analysis Tools

There are other decision analysis tools available, and some are listed below. Those included in this chapter were chosen because they are well developed, widely usable, and cover a range of complexity.

Optimization Methods

- Can address many or infinite alternatives
- Accept only quantitative inputs
- Find the optimal solution to a complex problem
- Identify feasible solutions that meet all limits
- Require a great deal of effort to develop and solve equations. Reaching stakeholder agreement on the model may be difficult.
- Uncertainty is not directly addressed

Kepner-Tregoe Decision Analysis

- Similar to the weighted scoring method, but evaluation scales are not developed
- Uncertainty not directly addressed

Benefit-cost Analysis

- Tries to make decisions independent of the preferences of decision makers
- Is data driven
- Minimizes the cost/benefit ratio across the affected groups
- Group that pays for the analysis may not receive benefits
- Often used by government agencies

Multiattribute Utility Analysis

- Extension of decision analysis and decision trees to address more than one performance criterion
- Plainly addresses uncertainty and value trade-offs
- Evaluation scales much the same as weighted scoring methods developed